immersion, was heated in hydrogen. The action would be represented by the formula

$$4Cu + SO_3 = CuS + 3CuO.$$

The above experiments prove that nearly the whole effect which is observed when copper is immersed in a solution of sulphate of copper or sulphuric acid is due to the presence of oxygen in the solution.

February 1, 1894.

Sir JOHN EVANS, K.C.B., D.C.L., LL.D., Vice-President and Treasurer, in the Chair.

A List of the Presents received was laid on the table, and thanks ordered for them.

I. "Insect Sight and the Defining Power of Composite Eyes." By A. MALLOCK. Communicated by LORD RAYLEIGH, Sec. R.S. Received November 28, 1893.

The optical arrangement of the simple eyes of Vertebrates is well understood, but as regards the action of the composite eyes of Insects and Crustacea less certainty has hitherto prevailed.

In the former class of eye a single lens, or its equivalent, forms an image on a concave retina, built up, as a sort of tesselated pavement, of the sensitive terminations of the fibres of the optic nerve, and, if the lens is perfect and the pupil large enough, the definition is limited by the distance apart of the nerve-terminations, for, in order that two objects may appear as two to the eye, they must subtend at least such an angle that their images as formed by the lens shall not fall on the same nerve-termination.

In the human eye the distance between the sensitive points on the retina is such that it subtends about a minute of arc at the optic centre of the lens, and in good eyes the optical part of the apparatus is sufficiently perfect to allow of this degree of definition being attained over a small part of the field of view.

For reasons, however, which will be given presently, such definition as this is not to be looked for in composite eyes.

The general plan on which all composite eyes are constructed is that of a convex retina having a separate small lens in front of each sensitive part, together with an arrangement of screens which allows

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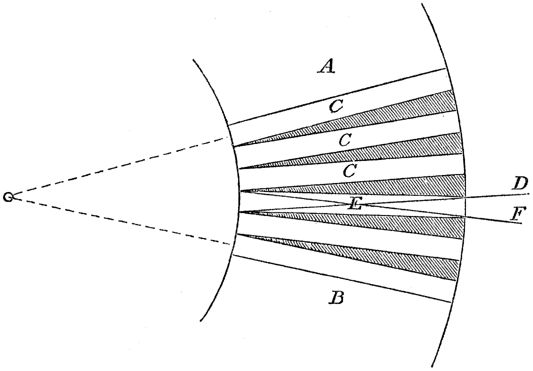
only that light coming from the immediate neighbourhood of the axis of the lens to reach the nerve.

The theory of "mosaic vision" put forward by Johannes Müller has been opposed by some physiologists, who appear to have considered that each lens of a composite eye formed a complete image which was taken cognizance of by the nerves as in the vertebrate eye, and that the whole of these images were in some way added together and arranged by the brain; I here bring forward some optical reasons which show that Müller's view is the true one.

On the supposition, therefore, of "one lens, one impression," the definition obtained by a composite eye will be measured by the total solid angle of view ÷ whole number of lenses in the eye.

The simplest form of composite eye would be a spherical shell, AB, fig. 1, perforated with radial holes, *c*, *c*, *c*, the diameter of these holes being small compared with the thickness of the shell.

FIG. 1.



If sensitive paper were placed in contact with the inner surface of the shell, it would be impressed with a picture of surrounding objects, for the light which reaches the bottom of any hole is limited to that making an angle less than $\frac{1}{2}$DEF with the axis of the hole, which angle is of course equal to the diameter of the hole ÷ half its length.

It is interesting to see what proportions would have to be given to an eye of this kind if the definition is to be as good as that of the human eye.

The limit of definition in this case being 1 min., the holes would have to be 7000 diameters long (since 1 min. is nearly 1/3500) and in order that diffraction may not interfere materially with the result,[*] the diameter of the holes should not be less then 2000 wave-lengths of light, say $\frac{1}{25}$ in. Hence the thickness of the shell will be 7000 × $\frac{1}{25}$ in., or 23 ft.

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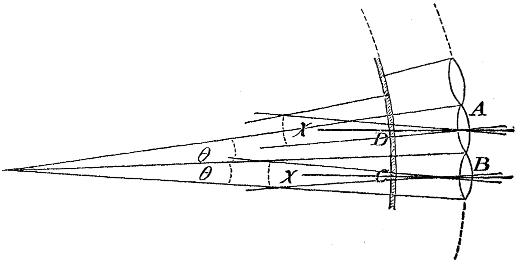
[*] It may be shown that the hole should not be much smaller than the first Huyghens zone of a system for which, if $\lambda/r = r/R$, R = the length of the hole, λ and r being the wave-length of light and the radius of the zone respectively. How

The radius of the sphere may be determined by the condition that, if the picture is to be continuous, the adjacent holes must just be in contact at the internal surface of the shell, that is to say the diameter of the hole, viz.: $\frac{1}{25}$ in., must subtend 1 min. at the internal radius of the shell, which makes this radius, therefore, 11 ft. 6 in.

Thus an eye of this construction and power of definition would consist of some part of a spherical shell of 34 ft. 6 ins. external radius, and 23 ft. thick, perforated with radial holes $\frac{1}{25}$ in. in diameter, and with their centres about $\frac{1}{8}$ apart on the external surface.

If still keeping 1 min. as the limit of definition, we substitute the arrangement actually found in composite eyes, and in place of the long tunnels in thick shell, we use short tunnels with a lens at the outer end of each tunnel, and a diaphragm at the inner end, pierced with a small central hole (fig. 2), the proportion of the eye will be determined in the first place by the diameter of the lens which will just define 1 min., and secondly by making that diameter subtend 1 min. at the centre of the sphere.

FIG. 2.



Now the size of the image of a point formed by a lens (as seen from the optic centre of the lens) is inversely as the diameter of the lens, and it takes a lens 4 ins. in diameter to define 1 second, *i.e.*, to separate points 1″ apart; hence the lens which will just define 1 min. is $\frac{4}{60}$ or 0·066 in. in diameter.

The radius at which 0·066 in. subtends 1 min. is about 19 ft.

It is evident, therefore, that no composite eye of practicable dimensions, acting as supposed above, could be made to give definition even approaching that of the human eye.

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much less than r the diameter of the hole may be is, to some extent, a matter of judgment depending on the degree to which it is considered desirable to reduce the intensity of the diffracted light.

If the diameter of the lenses is reduced, not only is the size of the sphere on which a given number of them would lie reduced, but, since the definition of each lens decreases with the diameter, a less number of lenses will be required to give the maximum definition attainable under the changed circumstances. Thus the radius of the sphere proper for the surface of a composite eye decreases as the square of the defining power of the separate lenses of which it is composed.

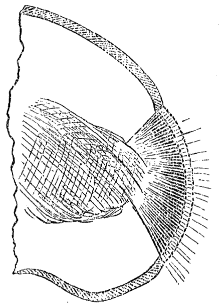
Let A and B (fig. 2) be two adjacent lenses, C and D the sensitive spots of the retina. Let θ be the angle between the axes of A and B, and χ the limit of definition of the lens. Then, if $\chi = \theta$, the image of a distant object in the axis of A will just fall clear of the sensitive point D, but, if $\chi > \theta$, both C and D will be illuminated by light from the same object.

Supposing, however, χ is less than θ, nothing will be gained in definition unless each lens has more than one sensitive point to operate on. If, then, we find that in actual composite eyes χ and θ are nearly equal, that is, that the difference in the direction in which the adjacent lenses point is nearly equal to the defining power of the lens itself, it becomes almost certain that each lens has only one sensitive point behind it.

The following table contains measures, recently made by me, of the diameters and angles between the axes of the lenses of various insect eyes, and, although the measure of the angle of view was necessarily rather rough, the agreement of the results, in the larger number of cases, with the supposition above made seems to me sufficiently remarkable.

In estimating θ there were two difficulties, one of which was that in many eyes the curvature of the surface was sharp at the margin and that the definition was probably bad there, and another that the line of sight of each lens was not always normal to the outer surface of the eye (fig. 3). Generally, I took the angle between the tangents

FIG. 3.



to the surface at the ends of a measured chord, choosing the chord so that the surface outside it should have fairly uniform curvature. The length of the chord was usually about three-quarters, or a little more, of that of the eye.

Taking the length of the chord as l, and r as radius of the sphere which best represents the surface of the eye, we have for the angle of view Θ,

$$\sin \tfrac{1}{2}\Theta = l/2r,$$

Species.	Length of body.	Greatest dimension of eye.	Diameter of aperture of ommatidium.	Angle between axes of adjacent ommatidia in minutes.	Defining power of lens of diameter *d* in minutes.
Diptera—			*d*.	θ	χ
1. Fly like a Bee, *Eristalis*	0·60	0·108	0·0012	56	55
2. Fly like a Wasp, *Sericomyia*	0·70	0·12	0·0016	48	71
3. Blow-fly, *Lucilla*	0·34	0·07	0·0018	84	35
4. Very small Flies, species not identified	0·20	0·026	0·00076	126	87
5. Ditto	0·13	0·021	0·0005	105	113
Hymenoptera—					
6. Hornet	1·0	0·152	0·0014	53	48
7. Wasp	0·7	0·088	0·0011	84	60
8. Bee	0·6	0·100	0·00072	50	90
9. *Chrysis*, scarlet and blue	0·4	0·045	0·00094	105	70
Lepidoptera—					
10. Small Cabbage White	0·8	0·059	0·00072	86	90
11. Red Admiral ...	1·0	0·072	0·00095	76	69
12. Small Copper ..	0·5	0·050	0·00071	100	93
13. Yellow under wing	0·75	0·064	0·00092	70	72
14. *Noctua*	0·7	0·060	0·00090	70	74
Dragon-flies—					
15. Large Dragon-fly, *Æschna cyanea*	3·5	0·282	Large lenses 0·0023 Small lenses 0·0016	48	41
16. *Libellula striolata*	2·5	0·191	Large lenses 0·0027 Small lenses 0·0015	50	45
17. Green Grass-hopper	1·1	0·057	0·0011	80	60
18. *Tipula*	1·0	0·027	0·00095	200	70

and $\theta = d/r$, where d is the diameter of the lens;

hence $$\theta = d/b \,.\, 2 \sin \tfrac{1}{2}\Theta.$$

The other columns of the table explain themselves.

On the whole, I think it must be concluded that Insects do not see well, at any rate as regards their power of defining distant objects, and their behaviour certainly favours this view; but they have an advantage over simple-eyed animals in the fact that there is hardly any practical limit to the nearness of the objects they can examine. With the composite eye, indeed, the closer the object the better the sight, for the greater will be the number of lenses employed to produce the impression; whereas in the simple eye the focal length of the lens limits the distance at which a distinct view can be obtained.

The best of the eyes mentioned in the table would give a picture about as good as if executed in rather coarse wool-work and viewed at a distance of a foot; and, although a distant landscape could only be indifferently represented on such a coarse-grained structure, it would do very well for things near enough to occupy a considerable part of the field of view.

II. "The Action of Heat upon Ethylene." By VIVIAN B. LEWES. Professor of Chemistry in the Royal Naval College, Greenwich. Communicated by Professor THORPE, F.R.S. Received December 6, 1893.

The decompositions of the simpler forms of hydrocarbons at an elevated temperature have always been recognised as a question of the greatest importance, as upon them is dependent a true conception of many of the actions taking place in the manufacture of coal gas and other kindred processes of destructive distillation.

Ethylene has in most cases been chosen as the hydrocarbon which would lend itself most readily to experimental researches upon this point, as, besides being one of the simplest, it is easily prepared, and is moreover found as one of the products in nearly all cases where organic compounds are subjected to distillation at high temperatures.

No sooner had the difference between ethylene and methane been recognised, than experiments were made by Deimann, Van Troostwyk, Lauwerenburg, and Bondt* to ascertain the action of heat upon the newly-formed compound, and the conclusions which they came to were that on heating no contraction in volume was observed, but that the tubes in which the decomposition was effected became coated with a black deposit, and drops of an oily body were formed, the gas

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* 'Annales de Chimie et de Physique,' 1st series, vol. 21, p. 48.

FIG. 3.